REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
01/00/88

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
SUMMARY OF WES ANALYSIS OF PROPOSED RECHARGE TRENCH SYSTEM FOR RMA, NORTH BOUNDARY

5. FUNDING NUMBERS

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ARMY ENGINEER WATERWAYS EXPERIMENT STATION. GEOTECHNICAL LABORATORY
VICKSBURG, MS

8. PERFORMING ORGANIZATION REPORT NUMBER
88155R01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ROCKY MOUNTAIN ARSENAL (CO.). PMRMA
COMMERCE CITY, CO

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

THIS DOCUMENT IS A SUMMARY OF AN ANALYSIS OF THE RECHARGE TRENCH SYSTEM PROPOSED FOR THE NORTH BOUNDARY

THE THREE SYSTEMS ANALYZED ARE:

A. TEN TRENCHES 100 FEET LONG AND 185 FEET APART
B. TEN TRENCHES 160 FEET LONG AND 170 FEET APART
C. THE SAME CONFIGURATION AS "B" BUT WITH A THINNER AND LESS PERMEABLE AQUIFER.

14. SUBJECT TERMS
TREATMENT

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE

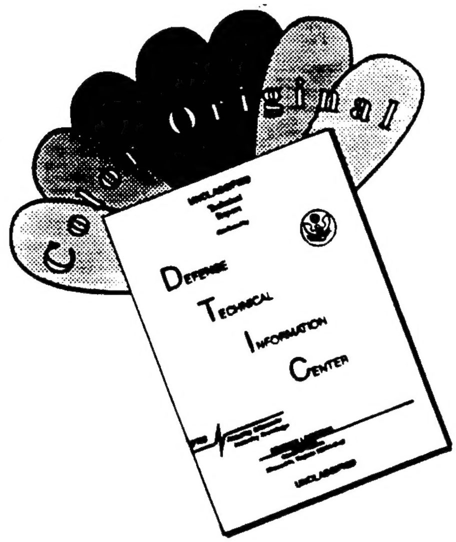
19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF COLOR PAGES WHICH DO NOT REPRODUCE LEGIBLY ON BLACK AND WHITE MICROFICHE.

88155R01 *
NON-DOT REVIEWED
2ND COPY

Summary of WES Analysis of Proposed Recharge Trench System for RMA North Boundary. 28 Jan 1988

In the summer of 1987 the Site Characterization Unit (SCU) of the Engineering Geology Group of the Geotechnical Laboratory, WES, was asked informally by the PMSO, Rocky Mountain Arsenal, to perform a quick analysis of the recharge trench system proposed for construction at the North Boundary Treatment System. The SCU agreed to develop analytical ground-water flow models or to use existing commercial, off-the-shelf models suitable for microcomputer (PC) use and to perform the analysis. Chief of the SCU during the analysis was James H. May. Group chief was Dr. Lawson Smith. Bill Murphy of the SCU performed the analyses. Several models were developed or selected and a number of analyses were made to evaluate various scenarios of aquifer characteristics and system operation. Three informal presentations of results were made between the summer and fall of 1987 to accommodate questions and suggestions from the PMSO.

The following is a summary of the results of the analyses. The summary is in three parts: (a) report of the first analysis, for which trenches were assumed to be 100 ft long and separated by 185 feet, with 10 trenches in the system. The permeability of the 8 ft-thick aquifer was assumed to be 400 ft/day; (b) report of a second analysis for which ten trenches were 160 ft long and 170 ft apart and for which a range of permeabilities and pumping (injection) rates were evaluated; and (c) report of an analysis for a trench geometry identical to that of analysis (b) but for a thinner and less permeable aquifer. In all cases, the trenches are simulated (modeled) by large cylindrical wells. The line of trenches is assumed to be 45 ft from and parallel to a slurry trench barrier which fully penetrates the aquifer.

Analysis of North Boundary Recharge Trenches. Analysis (a)

(a1) The analysis of the proposed recharge trenches for the North Boundary (see Figure 1) was performed using formulas derived from solutions of the Laplace equation (Reference 1). The purpose of the analysis was to predict the maximum rise (final elevation) of the water table or piezometric surface resulting from recharge to the aquifer at a given rate. The head (height of water table or piezometric surface above a reference datum) resulting from pumping or recharging the aquifer through one or more wells at steady-state conditions may be determined for any point (x,y) in the well field with the following equations:

$$(1)\quad h^2_{(x,y)} = \frac{1}{2\pi K} \sum_{i=1}^{n} Q_i \ln\left[(x-x_i)^2 + (y-y_i)^2\right] + C$$

which is the equation for unconfined flow derived from solution of the Laplace equation and application of the superposition principle (see Reference 1), where h =the steady-state head at point x,y;

K=permeability of the aquifer, in-ft/day; Q =discharge (or recharge) rate of well i; x ,y = location of well i; C= constant of integration determined by application of boundary conditions, and

(2) $$h_{(x,y)} = \frac{1}{2\pi Kb} \sum_{i=1}^{n} Q_i \ln\left[(x-x_i)^2+(y-y_i)^2\right] + C$$

which is the Laplace equation for confined flow, where b=aquifer thickness and Kb=aquifer transmissivity.

(a2) The equations were programmed in IBM Basic for execution on a PC.

(a3) Assumptions which apply to the solutions are (1) the well(s) completely penetrate the aquifer, (2) the aquifer has a horizontal base, is isotropic and homogeneous and extends to infinity, (3) all flow is laminar and horizontal (there is no vertical component of head). Because of the Dupuit assumption (that equipotential lines are vertical and therefore flow is horizontal) the equation for unconfined flow does not describe accurately the water table surface near the well where the strong curvature of the water table contradicts the assumption. Despite the limitations imposed by theoretical assumptions, the analysis is useful for estimating the rise in the water table resulting from pumpage into the aquifer.

(a4) Deviations from the assumptions by actual field conditions are: the aquifer is variable in thickness along the proposed recharge line, the base of the aquifer is not horizontal, the permeability may not be constant along the line, the actual recharge trenches will not fully penetrate the aquifer, and the trenches are simulated by cylindrical wells.

(a5) The following well-field/aquifer parameters were assumed for the north boundary recharge trench area: (1) permeability, K, is 400 ft/day, (2) the aquifer is 8 ft thick, or the initial water table is 8 ft above the base of the aquifer, (3) transmissivity, T, is 3200 ft /day, (4) storage coefficient for the confined aquifer is 0.001, (5) the initial water table is at elevation 5134 ft MSL and is flat, that is, there is no initial gradient.

(a7) The effect of the barrier (the slurry trench) is simulated by the method of images. A line of wells (trenches) is theoretically placed parallel to the line of real wells at twice the distance from the line of wells to the barrier (in this case, 90 ft), see Figure 1. The line of image wells recharges at the same rate as the line of real wells and produces the same effect on the aquifer of the real well field as a barrier would cause if just the real wells were recharging. Heads are then calculated for points in the real well field.

(a8) Steady-state heads were calculated for points along the line of real wells . The simulation used 30 real and 30 image wells

to model the trenches (three wells per trench). The constant of integration, C (equations 1 and 2) must be determined from the boundary condition h=H at r=re , where h is the head at a point and H is the static water level at a distance r from the center of the well array equal to the radius of influence re of the well array. A radius of influence of 11310 ft (10000+1310 ft to center of array) was used to determine C for the two analyses. A large r is necessary because the effective well field radius is large (length of array = 2600 ft). Superposition of effects of multiple wells requires that the well field size be negligible relative to r ; i.e., r from array edge= r from array center.

(a9) Both unconfined and confined analyses were run, but the confined case is believed to be more realistic for the north boundary because (1) the aquifer is at least semi-confined by the low permeability alluvium (CL, SC, etc.) overlying the lower sand and gravel alluvium and (2) the aquifer will rapidly become confined as recharge progresses. The confined analysis produced a maximum buildup of water only about 1 ft higher than the unconfined analysis. The heads along the line of recharge wells (trenches) after pumping in confined conditions to steady state are plotted on Figure 2.

(a10) Preliminary analyses using equal pump rates per trench resulted in mounding of water near the center of the trench array. The final analysis (Figures 1 and 2) incorporated variable, or weighted, pumping rates to flatten the resultant water table (or piezometric surface). Pumping rates for the final analysis varied from 12 gpm for the two center trenches (numbers 5 and 6, Fig 1) to 22 gpm for the outer pair of trenches on each end (numbers 1,2,9, and 10, Fig. 1). Similar manipulation could be used during actual pumping to distribute the final heads (water levels).

(a11) Only half of the resultant water table (piezometric surface) profile is shown because the effect is symmetrical along the line about the central point at x=1310, y=0. Cusps on the water table are the theoretical heads at each well. Additional sections of head were plotted for a line one ft from the barrier and a line perpendicular to the trench alignment and are shown in Figs 3 and 4 respectively.

(a12) Results of the analysis indicate that, within modeling and theoretical limitations, ten trenches 100 ft long, separated by 185 ft gaps, located 45 ft from the barrier, and injecting at a system rate of 184 gpm, will raise the water table or piezometric surface to about 10 ft above the current (static) level, or to an approximate elevation of 5144 ft along the line of trenches and near the barrier (Figures 2 and 3). The water level will drop off rapidly to the north (elev 5142 at 750 ft north of the recharge trench) as shown in Figure 4.

(a13) Two other analyses were run on the system using "canned"

PC programs. The Theis Well Field Model by Thomas Prickett calculates heads using the Theis well functions. The model allows up to 50 sources or sinks (25 real, 25 image) and permits the calculation of pre-steady-state heads (i.e, time can be a variable). The program also produces an X,Y,Z data file which can be passed to a contouring package for contouring of the heads. The Theis well field model (confined flow and all accompanying theoretical assumptions in effect) predicted a maximum build-up of the water table after 90 days of recharging of 12.9 ft above the static level. Trenches were simulated with two recharge wells per trench for a total of 20 real wells.

(a14) Similar results were obtained using a program from Texas A&M (TAMU). Documentation on the TAMU model was sketchy but the model apparently uses a modified version of the Laplace equations and superposition to compute drawdown.

(a15) The analyses discussed above indicate that 10-12 ft of rise in the water level (or piezometric surface) of the aquifer might be expected if 184 gpm recharge is attempted. The corresponding ground elevation would be approximately 5144-5146 ft which would place the water level in the trenches near ground level. If such a rise did indeed occur, the excess head created by the high level could be expected to increase the recharge capability (the driving force) of the trenches.

<u>Analysis of North Boundary Recharge Trenches.</u> Analysis (b)

(b1) To estimate the rise in the piezometric surface for a variety of conditions and to "bracket" the best and worst conditions, Q and K were varied and the head along the profiles was calculated. Recharge rates of 26, 50, 100, and 150 gpm were used. Permeabilities of 4, 40, 100, 300, 400, and 500 ft/day were used. Profiles along the centerline of the trenches, parallel to and one foot from the slurry trench barrier, and perpendicular to the line of trenches were constructed. Aquifer thickness was assumed to be 6 ft and radius of influence was set at 10,000 ft.

(b2) The effect of the slurry trench barrier was again simulated by the use of images. The array of real wells in this analysis represented 10 trenches, each 160 feet long, separated by 170 feet (proposed trench geometry had been changed by the contractor since previous analysis). The line of trenches was again 45 feet from the slurry trench. Each trench was represented (simulated) by 3 wells.

(b3) The resultant steady-state head along the trench centerline for K=4 and for the lowest pumping rate, Q=26 gpm, averaged about 180 ft, representing an elevation of about 5308 ft MSL. Further calculations for a K of 4 ft/day were considered unnecessary. Analyses were run for all four pumping rates for the other five permeabilities. Results of the analyses are summarized in Figure

5, which shows the "envelope" of acceptable pumping rates for given aquifer permeabilities assuming that the ground surface (maximum allowable elevation of steady-state piezometric surface) is 5145 ft MSL. By this analysis, all combinations of permeability and pumping rate below the envelope would produce acceptable heads. Figure 6 shows the rate of head increase with increasing pumping rate for two permeabilities. Figure 6 implies that at lower permeabilities an increase in pumping rate raises the head more than the same increase at high permeabilities.

<u>Analysis of North Boundary Recharge Trenches</u>. Analysis (c)

(c1) Subsequent discussions with the recharge trench contractor and with PMSO further revised the analysis. More recent field data indicated that the aquifer thickness should be modeled as about 6 ft and that the target ground surface elevation should be near 5140 ft MSL. It was further decided that the maximum pumping rate should be closer to 60 gpm because that figure was the approximate flux across the boundary area before installation of the treatment system. The Laplace equations were used to back-figure the field K of the aquifer that would be necessary to produce a head at the target elevation of 5140 ft at a recharge rate of 60 gpm. Calculation of K in this manner was appropriate because insufficient field data on transmissivities of the aquifer were available. The Laplace model yielded a value for permeability of approximately 275 ft/day.

(c2) PMSO wanted to estimate the time necessary to reach steady state (elev 5140 ft). The K of 275 ft/day, thickness of 6 ft and Q of 60 gpm were input as parameters in the Theis well field model (see analysis (a)), which allows calculation of head for an elapsed time. The analysis showed that after 7 days, the head had risen to elevation 5138.4 ft MSL, and that by 90 days the head was over the 5140 ft level. For estimation purposes, then, and under the assumptions and restrictions imposed by these analytical models, a steady state head of elevation 5140 ft MSL would be achieved in the trenches at a recharge rate of 60 gpm (total recharge over entire trench system), within approximately 3 months of start of pumping.

The use of analytical models to predict results of alternative schemes for operating recharge (or other) systems as described above is a useful management tool. The effectiveness of the tool is dependent on the availability of sufficient field data for describing the site hydrogeology and ground-water flow parameters (permeability, storage, nature of aquifer). It must also be realized that the analytical model must assume uniform conditions throughout the site, and that deviations in the field from uniformity, as in variable transmissivity and sloping interfaces, will decrease the model's effectiveness as a predictor. The models are, however, quickly accessed and developed for a given problem and a large number of operational scenarios and field conditions can be

simulated rapidly by using the power of microcomputers.

Reference(1): DeWiest, Roger, 1965. Geohydrology, John Wiley and Sons, Inc., New York (copy of pertinent chapter enclosed).

W.L. Murphy
Geotechnical Laboratory
WES

FIGURE 1.

PLAN OF TRENCH RECHARGE SIMULATION USING LAPLACE EQUATIONS, SUPERPOSITION, AND IMAGE WELLS (NORTH BOUNDARY

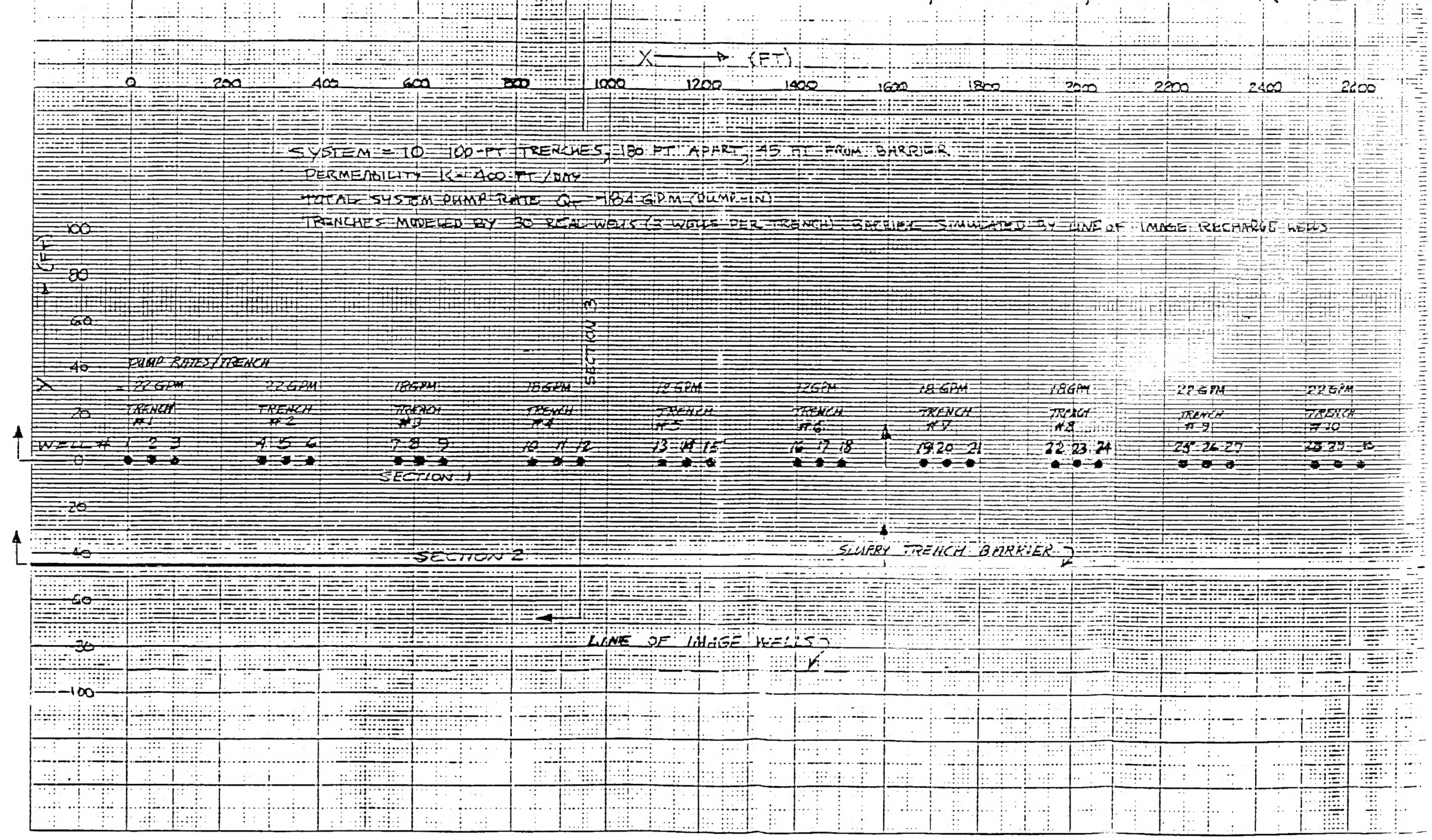


FIGURE 2 Vertical Cross-Section Through Line of Trenches. Variable Pumping Rates at Wells. Confined Aquifer Conditions. (Section Line is Y=0)

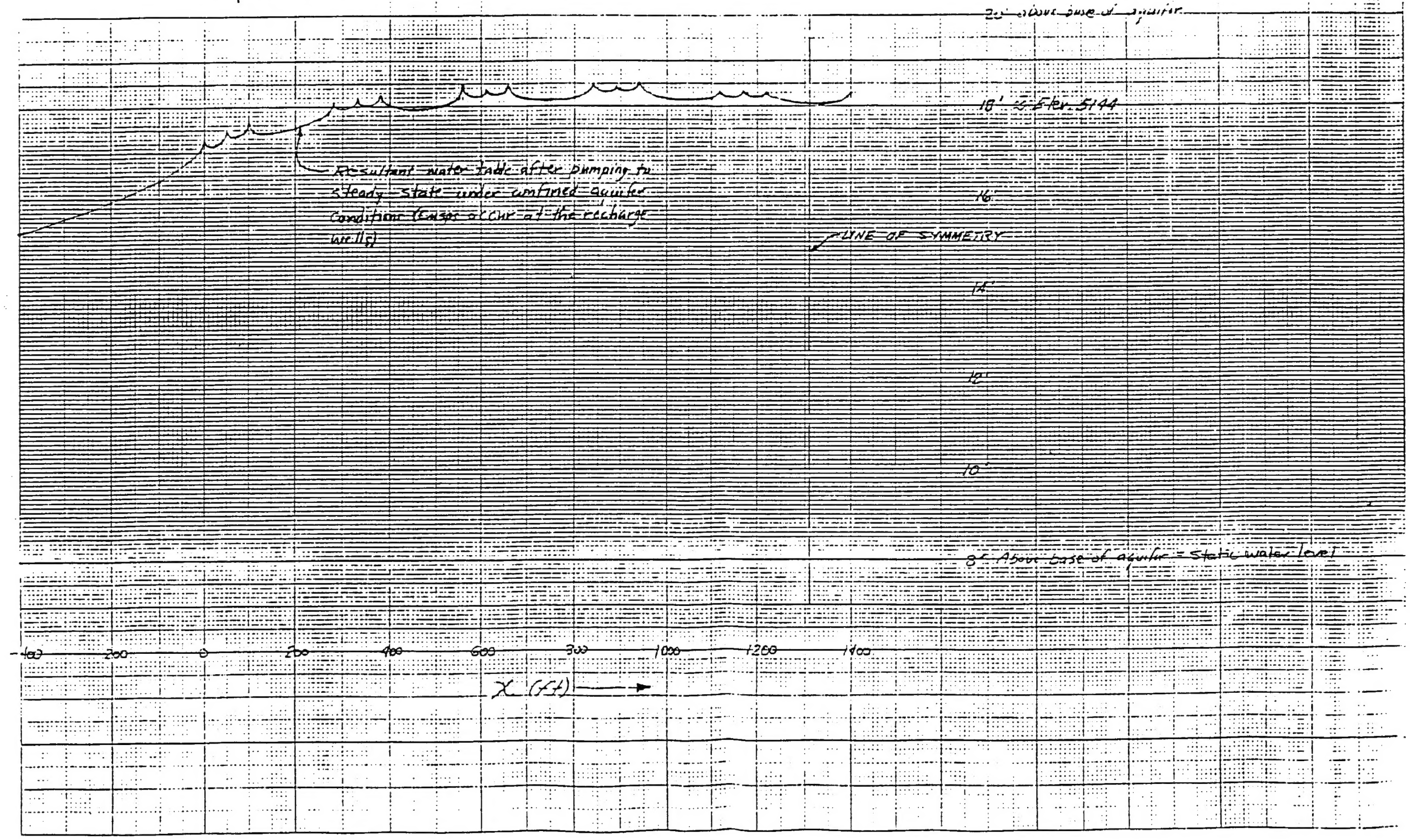


Figure 3. Vertical Cross-Section 1 ft from Barrier, Parallel to Barrier. Variable Pumping Rates at Wells. Confined Aquifer Conditions. Section Line is Y=-44. (Section 2)

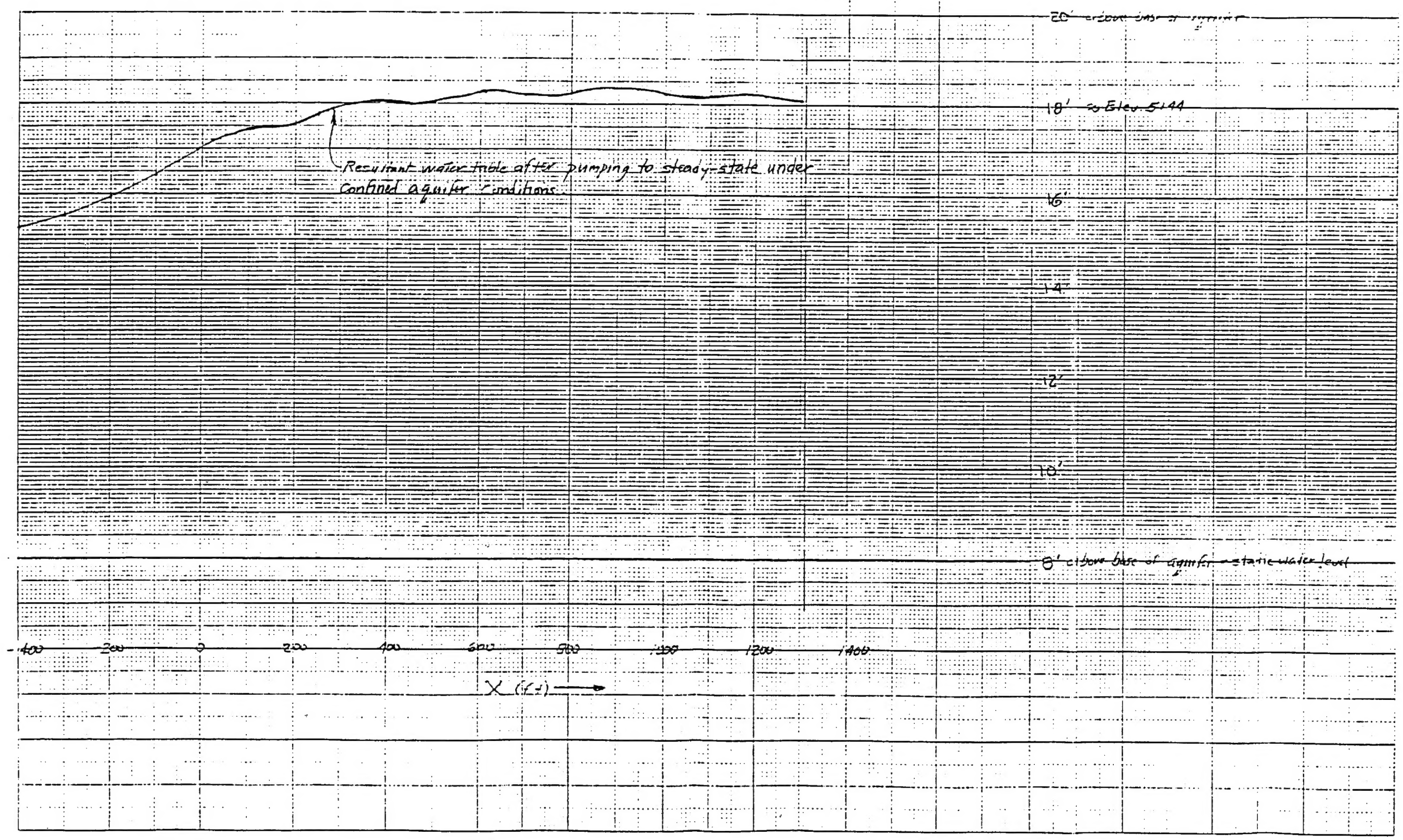
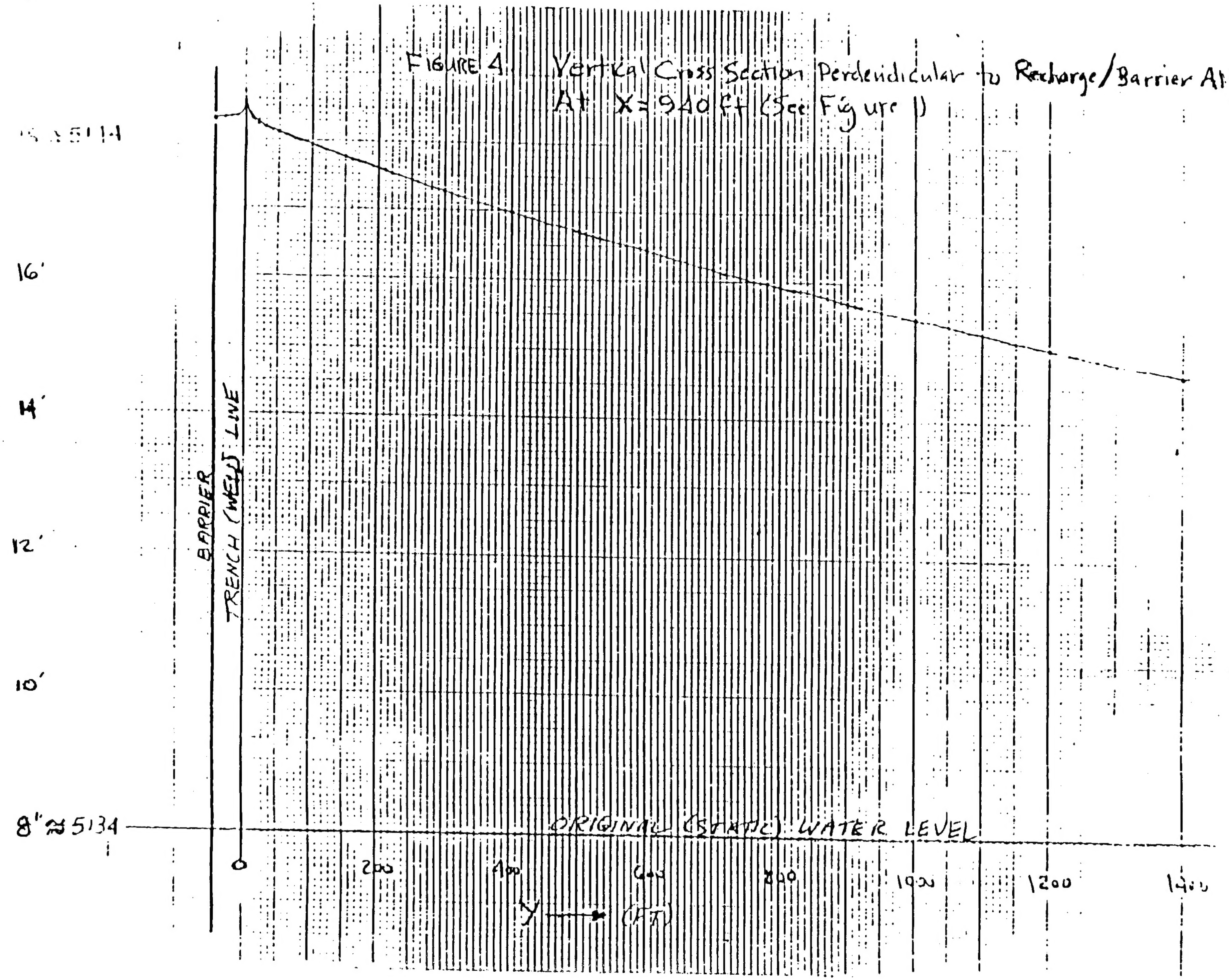


Figure 4 Vertical Cross Section Perpendicular to Recharge/Barrier Alignment At X = 940 ft (See Figure 1)

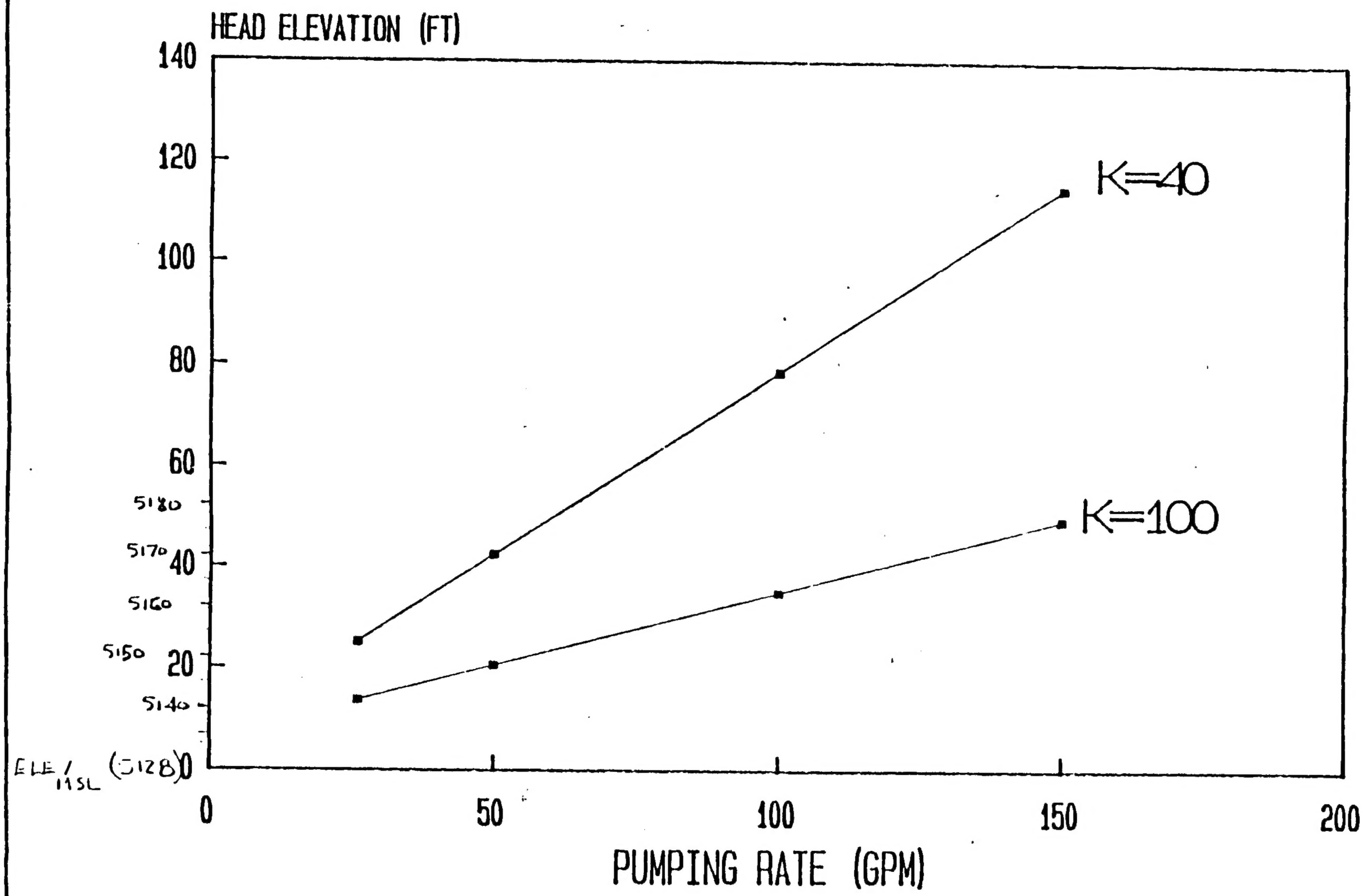


Approximate Maximum Steady-State Head for Various Q and K

K (ft/day)	Q (gpm) 26	50	100	150
4	5308	--	--	--
40	5153	5170	5206	5243
100	5142	5148	5163	5178
300	5137	5139	5144	5148
400	5136	5138	5141	5145
500	5136	5137	5140	5143

(head in Elev ft, MSL)

Figure 5



DATUM "0" IS AT ELEVATION 5128 ABOVE MSL (BASE OF AQUIFER)

Figure 6